Exploring Stratocumulus Cloud-Top Entrainment Processes and Parameterizations by Using Doppler

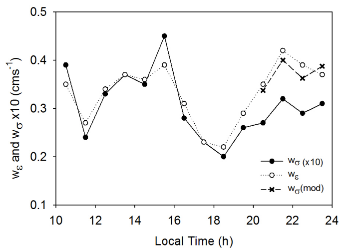
Research Highlight

Stratocumulus clouds are a particularly important component of the Earth's climate system due to their large impact on the radiation budget. But the parameterization of entrainment in these clouds is yet to be fully resolved, which leads to uncertainties in numerical model forecasts ranging from the mesoscale to the global scale. In this study we used observations collected at the Atmospheric Radiation Measurement (ARM) Climate Research Facility's Southern Great Plains (SGP) site during uniform non-precipitating stratocumulus cloud conditions for a continuous 14-hour period to examine cloud-top entrainment processes and parameterizations.

The observations from a vertically pointing Doppler cloud radar provide estimates of vertical velocity variance and energy dissipation rate (EDR) terms in the parameterized turbulent kinetic energy (TKE) budget of the entrainment zone. Hourly averages of the vertical velocity variance term formulation correlated strongly (r=0.72) with the dissipation rate term in the entrainment zone, with an increased correlation (r=0.92) when accounting for the night-time decoupling of the boundary layer. The correlation between the dissipation rate and the variance term has always been assumed in commonly used entrainment parameterizations, but this study provides the first observational confirmation of this relationship.

Independent estimates of entrainment rates for this case were obtained from an inversion height (mass) budget using the local time derivative and horizontal advection of cloud-top heights from ARM observations together with large-scale vertical velocity at the boundary layer inversion from reanalysis products. The mean entrainment rate from the inversion height budget during the 14-hour period was 0.74±0.15 cm s-1, and was used to calculate bulk coefficients for entrainment parameterizations based on convective velocity scale (w*) and TKE budgets of the entrainment zone. The hourly values of entrainment rates calculated using these coefficients exhibited good agreement with those calculated from the inversion height budget associated with substantial changes in surface buoyancy production and cloud top radiative cooling.

The results indicate a strong potential for making entrainment rate estimates directly from radar vertical velocity variance and the EDR estimates. Further, the results support the concept that eddy dissipation rates from radar observations can be used to estimate entrainment rates directly and that in some classes of models, entrainment rates could be estimated from parameterized or explicitly resolved dissipation rates. Using the eddy dissipation rate to determine entrainment rates has two major advantages. First, unlike estimates from the vertical velocity variance, no height scale or mixing length scales are needed. Second, statistically stable representations of the entrainment velocity can be made to allow for retrievals at higher temporal resolution than possible from the vertical velocity variance estimates. Thus, unlike in situ measurements from aircraft, the assumption of stationary and homogeneity on larger scales can be relaxed. The parameterization coefficients obtained in this proof-of-concept study (one 14-hour case) have inherent uncertainties associated with them because of the uncertainty in the estimates of the entrainment rate from the boundary layer mass budget. But these uncertainties can be reduced by applying the technique developed to several other cases using the ARM observations.



Entrainment velocities from the eddy dissipation rate (w#) and from the vertical velocity variance terms (w#x10) in turbulence kinetic energy (TKE) budget at the top of the boundary (cloud) layer. The variance term obtained using a reduced boundary layer depth to account for the decoupling (-×-) from 2030 to 2330 LST show an improved correlation with the dissipation term.

Reference(s)

Albrecht B, M Fang, and V Ghate. 2016. "Exploring Stratocumulus Cloud-Top Entrainment Processes and Parameterizations by Using Doppler Cloud Radar Observations." Journal of the Atmospheric Sciences, 73(2), 10.1175/JAS-D-15-0147.1.

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